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GB 2286247 A GB 2255641 A GB 2071852 A
EP 0723166 A1 EP 0438103 A2 WO 95/25385 A1
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UK CL (Edition O) G1N NCTL NCTM NDPQ NDPX
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(54) **Capacitive proximity or profile detector**

(57) A detector includes an array 10 of capacitive sensors which is connected to a multiplexer 15 for separately driving each of the sensors and determining the resultant electric field. The multiplexer is connected to two guard ring amplifiers IC1, IC2. The second guard ring amplifier (IC2) follows the voltages of the capacitive sensors and enables stray capacitance to be substantially eliminated by creating a simulated constant current source. Additionally, to counteract temperature drift effects a synchronous demodulator 17 which measures the size of any waveform generated by a sensor is provided with a pair of parallel switches SW1, SW2 connected to both input terminals of a further amplifier IC4.

The detector is particularly suited for use in determining the profile of an article, for example a foot for use in a foot gauge. The detector may also be used to monitor the number of individual articles or people crossing the field of the detector.

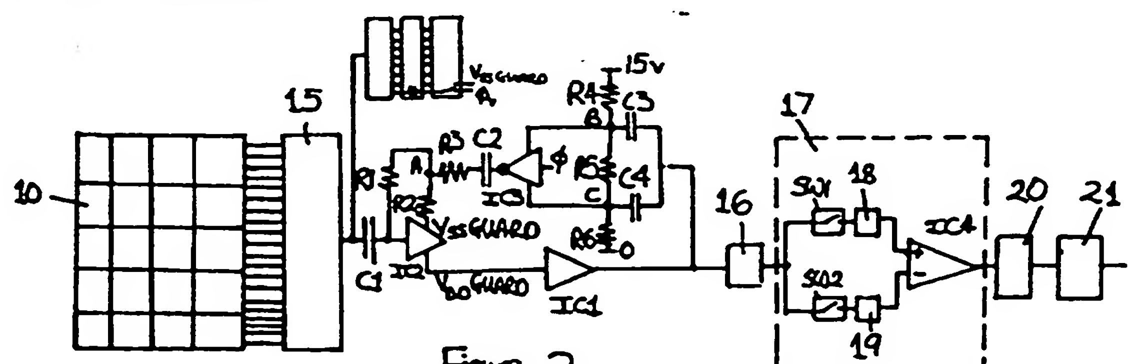

Figure 2

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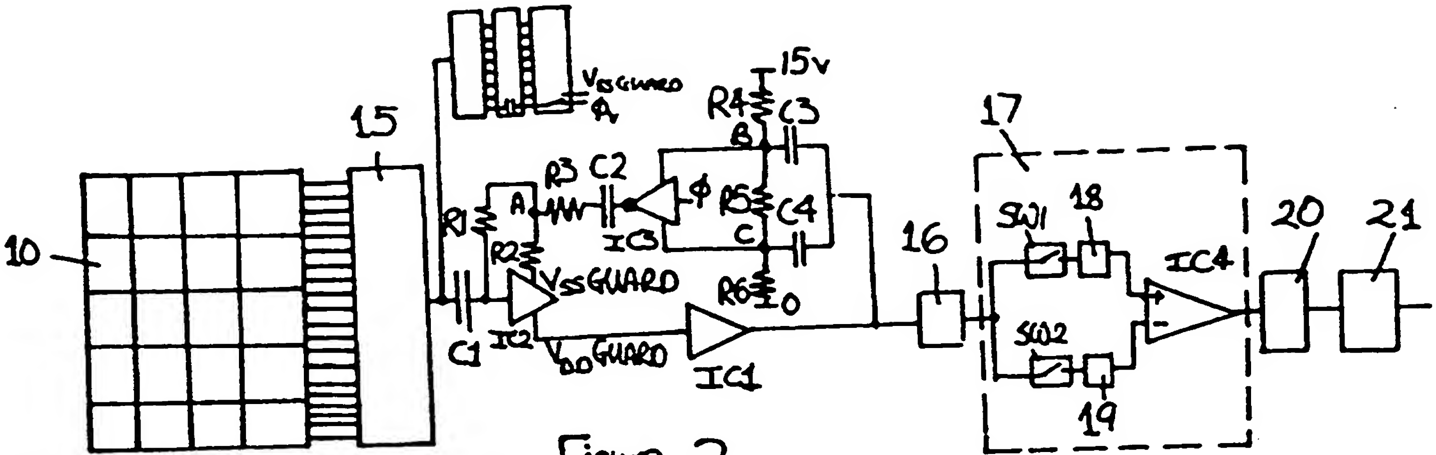

Figure 2

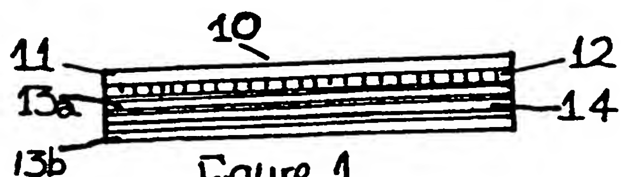

Figure 1

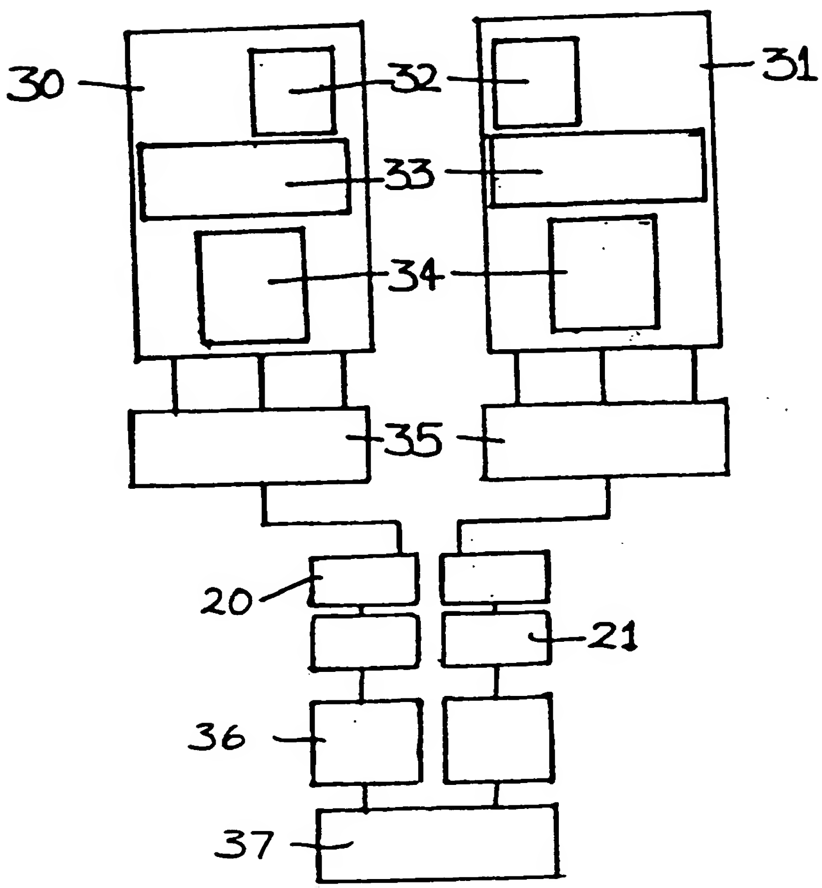

Figure 3

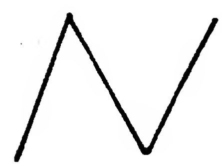

Figure 4a

Figure 4b

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DETECTOR

The present invention relates to a detector which employs capacitive coupling between an array of sensors and an article for determining the presence of the article. In particular the present invention relates to a detector which is suitable for use in determining the profile of the article.

Although capacitive sensors have the advantage that there are few if any moving parts and so there is little need for mechanical precision, to date conventional capacitive sensors have been used mainly in touch sensitive keypads and the like. Such sensors have not found popularity in more general applications as the sensitivity of the sensors is limited because of parasitic capacitance effects in the associated circuitry. This is especially the case where an array of a large number of individual sensors is involved.

The present invention seeks to provide a detector having an array of electric field sensitive sensors which alleviates the disadvantages described above of conventional capacitive sensors and which can be adapted to provide information on the fine detail of the profile of an article under examination. In this respect reference herein to the 'profile' of an article is intended as reference to the three dimensional external surface of the article.

The present invention provides a detector comprising an array of electric field sensitive sensors; means for positioning an article adjacent to but separated from the sensors; addressing means connected to the sensors for successively addressing each of the sensors; a driving arrangement connected to the addressing means for charging and discharging each of the sensors when addressed; an electric field monitor for measuring variations in the electric field generated by each of the sensors when addressed; and processing means for determining the

presence of the article in dependence on the measured electric field variations, the driving arrangement including a floating charging signal source arranged to follow the voltages of the addressed sensors thereby substantially eliminating parasitic capacitive effects.

In a preferred embodiment the floating charging signal source is in the form of a simulated constant current source. The effect of eliminating stray capacitance is most easily seen for a constant current charging source that is switched for then the stray capacitance effects are broken into two parts: (I) when the source is in transition and (ii) when it is in the constant current charging state. However there are beneficial effects of using a voltage divider chain with one end following the voltage on the addressed pad even where the charging source is exponential or sinewave and constant current or not.

The simulated constant current source may comprise a switching device connected to a voltage divider and to two voltage rails both of which vary to an equal extent in dependence on and following the voltage of the addressed sensor. Ideally the switching device is a CMOS which is driven with a square wave of a predetermined frequency. In the preferred embodiment a guard ring amplifier is provided connected to the addressing means with the floating charging signal source connected to one of the DC outputs of the guard ring amplifier, the second of the DC outputs being connected to the electric field monitor. Also, reference capacitors may be provided to allow correction of temperature drift effects and component differences as well as non-linearity in capacitance measurement.

Separately, the present invention also provides a detector comprising an array of electric field sensitive sensors; means for positioning an article adjacent to but separated from the sensors; addressing means connected to the sensors for successively addressing each of the sensors; a driving arrangement connected to the addressing

means for charging and discharging each of the sensors when addressed; an electric field monitor for measuring variations in the electric field generated by each of the sensors when addressed; and processing means for determining the presence of the article in dependence on the measured electric field variations, the electric field monitor including an amplifier both input terminals of which are connected to the output of the sensors via a corresponding pair of switches whereby temperature dependent effects are reduced.

The means for positioning the article adjacent the sensors may be a dielectric support. Reference capacitors may also be provided.

Preferably the detector is in the form of a profile detector adapted to determine the profile of an article, wherein the size of the individual sensors is substantially less than the size of the article and the processing means determine the profile of the article in dependence on the measured electric field variations. More than one array of electric field sensitive sensors may be employed to enable separate regions of an article's profile to be determined.

A foot gauge having a plurality of profile detectors as described above is envisaged in accordance with the present invention. Preferably separate profile detectors are provided for each major contact region of the foot with each profile detector being driven at a different frequency so that the profile of each of the regions may be detected simultaneously.

In a separate aspect the present invention provides a counter device for counting the number of individual articles crossing the counter device, comprising a detector as described above wherein the processing means determine the presence of an individual article and wherein there is further provided counter means for monitoring the total number of individual articles detected. The counter device is particularly suited to monitoring the number of living bodies crossing the detector. In this way,

information may be provided on the number of people and/or the number of animals entering or leaving a room or store, for example.

Embodiments of the present invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a view in section of a profile detector in accordance with the present invention;

Figure 2 is a circuit diagram of the profile detector of Figure 1;

Figure 3 is a schematic diagram of a foot measure incorporating profile detectors in accordance with the present invention; and

Figure 4a shows the preferred waveform employed with the present invention and Figure 4b shows the waveform with high frequency spikes caused by parasitic capacitive effects across the driven resistor R1.

The profile detector 10 shown in Figure 1 has a support surface 11 which is preferably made of a plastics material, for example acetate having a thickness of around 1mm. Beneath the support surface 11 an array of capacitive sensors 12, in the form of a plurality of rows and columns of electric field sensitive pads, are arranged. Beneath these sensors and insulated from them is a conductive surface 13a connected to the output of a 'guardamplifier' IC2. This isolates the sensors from other circuitry without adding stray capacitance as this plane follows the voltage on the addressed pad. Below this plane and insulated from it is the data collection circuitry 14. Underneath the data collection circuitry is another copper surface 13b connected to the output of a second lower impedance 'guardamplifier' IC1. This is provided to completely isolate sensitive lines from the date collection circuitry and sensitive vias to the sensor pads in the downward direction. The assembly is finished off with a thick strengthening backing of aluminium or steel connected to earth but insulated from the above layers. The assembly is normally constructed in ordinary multilayer PCB technology giving a very mechanically robust

construction.

In use, the profile which is to be measured of an article is placed on the support surface 11 facing towards the capacitive sensors 12. The acetate support surface 11 functions as a dielectric between the sensors 12 and the article as well as the air above the acetate at places where the article does not touch the acetate. The variation in the capacitive coupling between each of the sensors and the surface or profile of the article is measured to provide information on the variation in the separation between the sensors and the surface of the article facing the sensors 12.

Turning to Figure 2, each of the capacitive sensors 12 and reference capacitors is connected to an analogue time division multiplexer 15 the output of which is connected through a first capacitor C1 to a main amplifier ('guardamplifier') IC1 of gain 1. All unused lines are connected to V_{ss}GUARD (see below) by associated logic and analogue switches. The capacitor C1 acts to isolate the multiplexer 15 from the main amplifier IC1 and typically has a value of around 100μF. A guard ring amplifier ('guardamplifier') IC2 is connected between the first capacitor C1 and the main amplifier IC1. The guard ring amplifier IC2, also of gain 1, follows the voltages of the array of capacitive sensors and is used to provide DC power to the multiplexer and associated logic thus substantially eliminating stray capacitance to substrate in these circuits. This amplifier IC2 also drives the plane immediately under the sensors.

The main amplifier IC1 is connected to a first DC output V_{DD}GUARD of the guard ring amplifier IC2 which follows the voltages of the individual capacitive sensors as they are addressed. This amplifier drives the plane between the strengthening plane and the circuitry thereby substantially eliminating any stray capacitance to earth.

So that the parasitic capacitance in the driving resistor is eliminated by making its driven end follow the voltage of the addressed

sensor, a second output V_{ss}GUARD of the guard ring amplifier IC2 drives the main amplifier IC1 and this is connected to a simulated constant current source. The simulated constant current source drives a voltage divider having resistors R1, R2 and R3 typically having values of 330KΩ, 3KΩ and 100KΩ respectively. The first resistor R1 is connected between the input to the guard ring amplifier IC2 and the junction A of series resistors R2 and R3. The voltage divider is also connected to the output V_{ss}GUARD and is driven by a second capacitor C2. An integrated circuit switch IC3 preferably in the form of a 4007 CMOS drives capacitor C2. This switch is connected across the junctions B and C of three series resistors R4, R5 and R6 which are identical and which are held between ground and 15v rails. Each of the resistors R4, R5 and R6 are typically 10KΩ so that the junctions B and C of the series resistors between which the CMOS IC3 is connected are held at 10v and 5v respectively. Terminal ∅ of the switch IC3 is driven at a selected frequency so that it repeatedly switches between the voltages of junctions B and C. Ideally the terminal ∅ is driven using a square wave signal. Each of the junctions B and C is also connected via respective capacitors C3 and C4 to the output of the main amplifier IC1. Since the guard ring amplifier IC2 follows the voltages of the sensors in the AC sense this ensures a substantially fixed DC voltage difference is maintained across the voltage divider chain R1 and R2 and also a stepped down fixed voltage across R1 after the switch transition. This thus forms constant current circuitry after the switch transition. In more detail this constant current charging and discharging effect is obtained by applying a fixed voltage of approximately ±5 volts across the divider chain and a stepped down to ±0.5 volts across the charging/discharging resistor R1.

During the switch transition a ±0.5v spike is driven through the parasitic capacitance of R1, of approximately 0.2pF. The amplitude of the spike part of the final waveform is due to the ratio of the parasitic

capacitance of R1 and the external capacitance. Without the voltage divider chain described above these spikes would be ±5v. As 0.2pF can be bigger than the external capacitance to be measured (see Figure 4) the contribution of these spikes would be larger than the effect of the charging/discharging resistor giving a waveform that is not triangular. For a very small external capacitance to be measured it is necessary for the size of the capacitance across the driving resistor to be reduced to less than the external capacitance which in turn keeps the waveform triangular.

With the arrangement described above with the driving voltage stepped down by a resistive divider and with the other end of the chain AC connected to the guard ring amplifier IC2 the capacitive driving effect can be reduced to any desired degree. Also external capacitive effects on the junction of the two resistors in the driving chain and the driven resistor R1 are not a problem as the junction A between resistors R2 and R3 in the voltage divider can have a low impedance so it is not sensitive to the placement of the components near earthed points of the circuitry.

Preferably a triangle waveform is used because of its approximation to a sinewave with extra circuitry a stable true sinewave could be generated but at the expense of slight temperature stability gains. Although the profile detector could be used with other waveforms such as a square wave which has high speed transitions in the waveform, a temperature stable driving capacitor with a narrow tolerance is difficult to obtain. With the present profile detector this is no problem with the resistive driving circuitry since 1% tolerance resistors are easily obtained with excellent temperature coefficients.

A larger divider chain can reduce the ±0.5v spike to any desired size with R1 made proportionally smaller to provide the correct charging current for the desired size of waveform. This is an added benefit of the voltage divider chain described as for small measured capacitance,

the R1 value required would otherwise be greater than 10MΩ. As mentioned earlier, with the profile detector described herein R1 can be much smaller than this, for example 330KΩ which significantly reduces the susceptibility to stray capacitance effects. Finally since the divider chain uses small value resistors it can be replaced with a preset allowing easy setup of the driving current and the resultant waveform size. Also all points in the circuit are of low impedance and thus insensitive to stray capacitance including the slider on the preset.

The output of the main amplifier IC1 is connected to a low pass filter 16 and then to a synchronous demodulator 17 which enables the size of the waveform from the low pass filter 16 to be measured. This low pass filter makes the triangle waveform more sinewave like so the synchronous demodulator is dealing with lower frequencies. The synchronous demodulator 17 consists of a pair of parallel switches SW1 and SW2 which are connected to the positive and negative terminals respectively of an amplifier IC4 of gain 1. Respective low pass filters 18, 19 are also provided between the switches SW1 and SW2 and the terminals of the amplifier IC4. The synchronous demodulator is arranged so as to reduce the effect of any temperature drift by ensuring that both input terminals of the amplifier IC4 are connected to the outputs of the switches SW1 and SW2. In this way any temperature dependent drift especially that due to charge injection from the switches is cancelled out between the two inputs to the amplifier. This type of switching demodulates all odd harmonics of the input waveform. To attain maximum stability though the earlier circuitry which removes the parasitic capacitance effect of the driving resistor is required so that the demodulator is only fed with a waveform near to a sinewave. Any non-sinewave components will be that due to external or internal noise and will be rejected by the filter.

The switches in the synchronous demodulator can be turned

off before the multiplexer addresses another pad and not turned back on until any noise caused by the switching has subsided.

The output of the synchronous demodulator 17 is connected to an analogue-to-digital converter (ADC) 20 the output of which is connected to a microprocessor 21 which manipulates the data from the sensors 12 and corrects it with data from the reference capacitors to generate a three dimensional map of the profile of the article. The use of reference capacitors, typically employing interdigital capacitor construction with copper on a pcb, allows correction of temperature drift effects and component differences as well as non-linearity in capacitance measurement.

In Figure 3 one implementation of the profile detector of Figures 1 and 2 is shown. In Figure 3 a foot gauge is shown which enables the profiles of left and right feet to be measured at the same time. In particular, the curves in three dimensions of the feet are determined. The foot gauge includes two sets 30, 31 of three profile detectors 32, 33, 34 with each of the profile detectors 32, 33,34 corresponding to the profile detector of Figures 1 and 2. The profile detectors 32, 33, 34 are positioned adjacent the major surface contacting regions of each foot to be measured. Thus detectors 32 determine the profile of the big toe for each foot, detectors 33 determine the profile of the ball of each foot and detectors 34 determine the profile of the heel of each foot. This information can be used to generate a 3-D profile of the entire foot and to provide specific measurement of selected parts of the foot, i.e. length, width and arch height, for example. These measurements can be used for example in the manufacture of fitted insoles or entire shoes. Each of the individual sensors is substantially smaller than the foot and indeed is substantially smaller than the major surface contacting regions of the foot. The output from each of the synchronous demodulators 17 for each set is separately multiplexed in a respective first frequency division multiplexer 35. Each of

the profile detectors 32, 33, 34 are therefore driven at different frequencies, for example 400, 450, 500, 550, 600, 650 KHz.

The human body has a capacitance of greater than 100pF to the external world. The capacitance between any one of the capacitive sensors 12 and the foot will be a maximum of 0.3pF depending on the separation. Thus the model for the capacitance of the foot as seen by the sensor is that of 0.3pF in series with 100pF. This is 0.299pF so we can treat the 100pF as if the body is shorted to earth.

The multiplexer used to address each individual sensor pad and necessary associated logic to connect any unaddressed lines to V_{ss}GUARD is powered through V_{dd}GUARD and V_{ss}GUARD. This is both a low AC and DC impedance. As the multiplexer is powered by a low impedance, any noise generated by the multiplexer is not passed to the sensor and so does not appear in the resultant signal.

Each of the sensors in any one of the profile detectors is driven sequentially with each of the profile detectors being driven simultaneously and at different harmonically unrelated frequencies. This is possible because of the effectiveness of the synchronous demodulators in rejecting frequencies received from adjacent profile detectors. The data from each of the profile detectors is multiplexed and then passed to ADCs 20 and from there to the microprocessors 21. The data is then passed through serial links 36 to a common processor 37 to determine the variation in separation of the surface of the foot from the sensors and thereby the landscape or profiles of the bases and edges of each foot. Moreover, by virtue of the differences between the permittivity of the foot and any covering, such as a sock, it is possible for the profile of the foot to be detected through such a covering. The sock being essentially transparent to the capacitive sensor. With the foot gauge the profile of the foot can be scanned using for example 2,000 sensors in less than 5 secs., e.g. 1.5 secs., to 12 bit accuracy.

Although the detector has been described above in terms of its function as a profile detector and in particular for its use as a foot gauge, the detector may be employed in varied applications where the presence or absence of an article (or person) is to be detected rather than the profile of the article. For example, the detector may be arranged to count the number of people who cross the detector. For this application, the individual capacitive sensors are somewhat larger than for the foot gauge application, for example approximately 900 cm^2. The detector is located in the floor and has a support surface across which people will walk. The associated circuitry is similar to that shown in Figure 2 and is located away from the site of the sensor array.

The detector monitors changes in the electrical field of the sensors to determine the presence of a body over the sensors. The resultant information is then analysed to produce a count of the number of people crossing the detector, for example repeated counts caused by people standing still over the sensor array are excluded. The detector can also be used to determine the direction of travel, so that the total number of people within a store can be monitored. The detector may also be used on the entrance to a bus or other public vehicle. In combination with pressure sensors, the detector may be used to discriminate between adults and children or pets crossing the detector. Also, the detector may be employed as part of a security system where the individual gaits of different people crossing the detector may be identified and matched with records of authorised personnel. Of course the detector may also be used to detect the presence or number of other animals or inanimate objects, for example in an automated manufacturing line.

The detector and foot gauge described herein monitor capacitive effects at a distance above the sensors resulting from the presence of an article or person, for example. The sensors are not dependent on contact and instead provide measurement at a distance.

It will be understood that variations and alterations to the sensors and associated circuitry described herein are envisaged without departing from the profile detector described which enables substantially parasitic capacitance free measurement.

CLAIMS

1. A detector comprising an array of electric field sensitive sensors, means for positioning an article adjacent to but separated from the sensors; addressing means connected to the sensors for successively addressing each of the sensors; a driving arrangement connected to the addressing means for charging and discharging each of the sensors when addressed; an electric field monitor for measuring variations in the electric field generated by each of the sensors when addressed; and processing means for determining the presence of the article in dependence on the measured electric field variations, the driving arrangement including a floating charging signal source driving a voltage divider chain arranged to follow the voltages of the addressed sensors.

2. A detector as claimed in claim 1, wherein the floating charging signal source comprises a simulated constant current source.

3. A detector as claimed in claim 2, wherein the simulated contant current source includes a switching device connected to a voltage divider and to two voltage rails both of which vary to a substantially equal extent in dependence on and following the voltage of the addressed sensor.

4. A detector as claimed in claim 3, wherein the switching device is a CMOS driven with a square wave of a predetermined frequency.

5. A detector as claimed in any one of the preceding claims, wherein a guard ring amplifier is provided which is connected to the addressing means and has the floating charging signal source connected to a first DC output of the amplifier with a second DC output being connected to the electric field monitor.

6. A detector comprising an array of electric field sensitive sensors; means for positioning an article adjacent to but separated from

the sensors; addressing means connected to the sensors for successively addressing each of the sensors; a driving arrangement connected to the addressing means for charging and discharging each of the sensors when addressed; an electric field monitor for measuring variations in the electric field generated by each of the sensors when addressed and processing means for determining the presence of the article in dependence on the measured electric field variations, the electric field monitor including an amplifier both input terminals of which are connected to the output of the sensors via a corresponding pair of switches.

7. A detector as claimed in either one of claims 1 or 6, wherein the means for positioning comprises a dielectric support.

8. A detector as claimed in claim 7, wherein the dielectric support consists of acetate.

9. A detector as claimed in any one of claims 1 to 8, wherein there is further provided counting means for counting the number of detected individual articles passing the detector.

10. A detector as claimed in claim 9, wherein the electric field monitor is adapted to detect variations in the electric field generated by each of the sensors caused by the presence of a living body and wherein the counting means counts the number of bodies passing the detector.

11. A profile detector comprising a detector as claimed in any one of claims 1 to 8, wherein each of the electric field sensitive sensors is smaller than the article to be detected and wherein the processing means are adapted to determine the profile of the article.

12. A foot gauge comprising one or more profile detectors as claimed in claim 11.

13. A foot gauge as claimed in claim 12, wherein at least two separate profile detectors are provided for determining the profile of major contact regions of the foot and wherein the sensor array of each profile detector is driven at a different frequency.

14. A detector substantially as hereinbefore described with reference to and as shown in Figures 1 to 4.

The Patent Office

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Application No: GB 9703169.4
Claims searched: 1 to 5, 7 to 13

Examiner: A J Oldershaw
Date of search: 1 June 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G1N CTL, CTM, DPQ, DPX

Int Cl (Ed.6): G01B; H03K

Other:

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB2286247A (M.I.T.)	
A	GB2071852A (ROLLS-ROYCE)	
A	EP0723166A1 (CARLO GAVAZZI)	
A	WO95/25385A1 (TANISYS TECHNOLOGY)	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

The Patent Office

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Application No:	GB 9703169.4	**Examiner:**	A J Oldershaw
Claims searched:	6 to 13	**Date of search:**	5 September 1997

Patents Act 1977
Further Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G1N NCTL, NCTM, NDPQ, NDPX

Int Cl (Ed.6): G01B; H03K

Other:

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB2255641A	(TSUDEN KK)	
A	EP0438103A2	(WEISS)	
A	US5172065	(WALLRAFEN)	
A	US4891627	(MURAO)	

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Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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